PROGRAMMABLE MULTI-CHANNEL AMPLITUDE AND PHASE SHIFTING CIRCUIT

RIGHTS OF THE GOVERNMENT

[0001] The invention described herein may be manufactured and used by or for the Government of the United States for all governmental purposes without the payment of any royalty.

BACKGROUND OF THE INVENTION

[0002] The invention relates to providing multiple sinusoidal voltage signals at the same frequency or simultaneously sweeping in frequency, each having a programmable amplitude and phase.

[0003] Several applications in structural dynamics testing and active vibration and acoustic control require multiple excitations programmed at specific amplitudes and phases. The excitations may be used to simulate rotational forces, excite particular vibration modes of a structure, or cancel unwanted vibration or noise. These multiple excitations require multiple channels of signal generation with programmable amplitude and phase.

[0004] A simple, prior art method of phase shifting a signal is to pass it through an analog circuit with an inductive and resistive load. The amount of phase the circuit provides could be controlled with a programmable resistor which changes the phase response of the circuit. The problem with this method is that the change in resistance also changes the amplitude response of the circuit. Therefore, this method has the disadvantage that only an arbitrary phase or amplitude can be commanded on each channel, but not both.

[0005] Another prior art method is where both amplitude and phase can be adjusted using a single-channel phase shifter. Multiple single-channel phase shifters can be referenced to the same input sinusoid to create multiple phased sinusoid outputs. The problem with this system is its lack of programmability. The user must manually adjust a gain and phase knob on each channel. At best, these adjustments would have to be made any time the user desired to change his test set-up with a different arrangement of amplitudes and phases on the channels. At worst, these adjustments would have to be made for every frequency change when controlling actuators with slightly different frequency responses. Each single phase shifter is programmable and can be controlled via standard GPIB instrument control. One disadvantage of this system is that each module can only adjust the phase and not the amplitude of each channel. Also, this system uses a programmable time delay to cause the phase shift. The user is required to manually input (via software) the time delay directly or the frequency of the input waveform. Therefore, the second disadvantage is

that automatic phased frequency sweeps are not possible with this system and changing frequency manually to perform a sweep test would be cumbersome and time consuming.

[0006] Another prior art approach for producing programmable amplitude and phase-shifted sinusoids is to use multiple phase-locking commercial function generators. The disadvantage of this method is its expense for large numbers of channels such as those that might be needed to excite a bladed disk. (Some bladed disks have over 100 blades).

[0007] Therefore, there exists a need in the art for an inexpensive programmable multiple channel amplitude and phase shifter which can operate either at a single frequency or sweep in frequency. The traveling wave excitation system phase shifter chassis method and device of the invention is compact, inexpensive, and versatile when compared to customary methods for generating traveling wave excitation signals.

SUMMARY OF THE INVENTION

[0008] The programmable, multiple channel amplitude and phase shifting circuit device and method of the invention is compact, inexpensive, and versatile when compared to customary methods for generating traveling wave excitation signals that would require using an equivalent number of commercial function generators. The method and device of the invention produces up to 56 simultaneous sine waves that are phase shifted with respect to one another. The preferred arrangement of the invention utilizes a standard personal computer 24-channel digital interface port by which the amplitude of each sine wave can be adjusted. Ideally, the invention permits operation of two chassis - for up to 112 channels of phased sinusoids - from a single computer interface port.

[0009] It is therefore an object of the invention to provide an inexpensive, multiple channel amplitude and phase shifter.

[0010] It is another object of the invention to provide a programmable multiple channel amplitude and phase shifter

[0011] It is another object of the invention to provide a compact_programmable multiple channel amplitude and phase shifter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG 1 shows a conceptual amplitude and phase shifting circuit.

[0013] FIG 2 shows a schematic of the amplitude and phase shifting circuit of the invention.

[0014] FIG 3 shows an amplitude and phase shifting circuit of the invention.

[0015] FIG 4 shows a 28 channel phase shifting circuit of the invention.

[0016] FIG 5 shows a program for controlling the programmable, multi-channel amplitude and phase shifting circuit of the invention.

DETAILED DESCRIPTION

[0017] The amplitude and phase shifting circuit of the invention creates phase shifted sine waves with the following trigonometric identity:

$$A\sin(\omega t+\theta)=B\cos(\omega t)+C\sin(\omega t) \quad (1)$$

$$B=A\sin(\theta) \quad (2)$$

$$C=A\cos(\theta) \quad (3)$$

where *A* is the desired output amplitude (volts), ω is the sinusoid frequency (Hz), *t* is time (sec), θ is the desired phase angle (radians), and *B* and *C* are constants.

[0018] The method in equations (1-3) was implemented using two programmable operational amplifiers (for gains *B* and *C*) and one summing operational amplifier per channel. A personal computer sets *B* and *C* using a National Instruments™ digital output card and LabVIEW™ software. These digital output cards and software are described by way of example are not intented to limit other arrangements of invention. A standard two-channel function generator is used to supply the required $sin(\omega t)$ and $cos(\omega t)$ waveforms. However, any traveling wave generating device may be used.

[0019] A conceptual diagram of this circuit for a single channel is shown in FIG.1. Two programmable operational amplifiers are shown at 100 and 101. A summing operational amplifier is shown at 102 and $sin(\omega t)$ and $cos(\omega t)$ waveforms, generated by a two-channel function generator, are shown at 103. The circuit shown in FIG. 1 is then repeated for as many channels of signal generation.

[0020] FIG. 2 shows a schematic of an amplitude/phase shifting circuit board with each printed circuit board implementing four channels of the output circuit show in Figure 1. Each board contains a matrix of selector jumpers that allow assignment of its four channels, shown at 200 through 203, among the 28 select lines coming from the demultiplexer chips, shown at 204. The circuit board has 8 programmable gain operational amplifiers, illustrated at 205-212. Each programmable gain amplifier is connected to 8 data lines, 4 control lines, and 1 chip select line from the motherboard. The chip select line must be low for the programmable gain amplifier to respond to any control or data lines. The 4 control lines determine the timing and sequencing of reading the data lines, storing the data in a buffer, and changing the gain of the

operational amplifier. The 8 data lines send a 12 bit digital number corresponding to a gain between 1 and –1. The input sine and cosine wave, shown at 213 for the first channel, are input to the programmable gain operational amplifiers and then summed with another operational amplifier, the summing operational amplifiers shown at 214 through 217 in FIG. 2 and as shown at 102 in FIG. 1. The final phase and amplitude shifted sinusoid is then sent to an output connector at the top of the card. The output connector is then wired to the BNC patch panel on the outer case.

[0021] FIG. 3 shows a top view of an amplitude and phase shifting circuit of the invention. The operational amplifiers of FIGs. 1 and 2 are shown for two channels at 300 and 301 in FIG. 3.

[0022] In a preferred arrangement of the invention, the amplitude and phase shifting circuit of the invention consists of an enclosure, a motherboard, a demultiplexer circuit board and an amplitude/phase shifting circuit board. The overall installed 28 channel phase shifting circuit of the invention is shown in FIG.4. The enclosure is shown at 400 in FIG. 4 and consists of a card cage to hold the printed circuit boards interfaced with the motherboard. The enclosure also provides a front panel for the sine and cosine input signals and the phase shifted outputs. The enclosure mounts into a standard 19 inch electronics rack, illustrated at 401.

[0023] The motherboard, illustrated at 402, is used to supply the demultiplexer circuit board and the amplitude and phase shifting circuit boards, illustrated at 403, with power, digital control lines, and the sine and cosine input signals. One circuit board in the motherboard is reserved for a demultiplexer circuit board, illustrated at 404 in FIG. 4.

[0024] The demultiplexer circuit board consists of a 50-pin ribbon cable connector to accept the digital control lines coming from digital output card in a personal computer. Five digital control lines are rounted from the pin connector to two 4-line to 16-line demultiplexer chips. The rest of the digital control lines from ribbon cable connector are routed directly to the motherboard to be available to the amplitude/phase shifting circuit boards.

[0025] The demultiplexer output lines are routed into the motherboard so that they are available to the amplitude and phase shifting circuit boards. Each

demultiplexer output line is connected to a different multiplying operational amplifier chip select line on the amplitude/phase shifting circuit board. The demultiplexer chips select one amplifier at a time to have its gain changed when the user desires a new amplitude or phase to be set on one of those channels.

[0026] The programmable multiple channel amplitude and phase shifting circuit of the invention must be controlled with some type of digital output. In the preferred arrangement of the invention, the circuit is controlled with a digital output card from a personal computer. However, other methods may be implemented and a digital output card is described by way of example, only. The digital output card interfaces with the phase shifting circuit through a 50 pin ribbon cable. The user interfaces with the digital output card with some type of software. The current configuration uses LabVIEW™ software. The user simply types in the desired amplitude and phase on each channel and the LabView™ software sends the appropriate digital commands to the programmable gain amplifiers to change their gains according to equations (1-3).

[0027] FIG. 5 shows LabVIEW™ software control panel which controls the programmable multi-channel amplitude and phase shifting circuit as well as other equipment involved in the traveling wave test.

[0028] There are many advantages to the method and device of the invention. For example, prior art methods of traveling wave excitation for turbine engine bladed disks adjusted the excitation signal gains to correct for variations in the exciter frequency responses. This was necessary to produce equal amplitude excitation on all blades. Although the frequency response variations involved phase as well as amplitude variations, only amplitude corrections could be made with previous systems. However, the amplitude and phase shifting circuit of the invention can correct for both amplitude and phase differences between exciters. This results in a more perfect simulation of the rotating forces experienced by turbine engine airfoils. Such precise excitation is important when studying the forced response of bladed disks which can be very sensitive to slight perturbations in structural and forcing properties.

[0029] From a practical viewpoint, there are also advantages to the method and device of the invention. For example, the programmable multi-channel amplitude and phase shifting circuit significantly reduces the per-channel cost for providing multi-

channel amplitude and phase shifted sinusoids. This cost reduction can be significant for many applications where large numbers of amplitude and phase shifted signals are required. Examples include exciting turbine engine bladed disks containing many airfoils, active vibration control, and multiple shaker control for phased resonance testing.

[0030] There are many potential alternative modes of the invention. The amplitude and phase shifting circuit can be used for any application where multiple sinusoidal signals with different amplitudes and phases but identical frequencies are required.

[0031] While the apparatus and method herein described constitute a preferred embodiment of the invention, it is to be understood that the invention is not limited to this precise form of apparatus or method and that changes may be made therein without departing from the scope of the invention which is defined in the appended claims.